National Aeronautics and Space Administration

Thermal Runaway of Silicon Anode Pouch Cells in Electric Aircraft Battery Design

IAPG Chemical Working Group

Safety Panel

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Outline

- **Aviation Battery Motivation**
- **Cell Background**
- **Thermal Runaway Results**
  - Uncompressed cells
  - Compressed cells
  - Cells w/ aerogel layers
- **Next Steps**

Electric Aircraft Propulsion (EAP) Battery Development Motivation

- **> 400 Wh/kg required at the system level**
- **1000's of cycles with high reliability & limited maintenance**
- **High power requirements during takeoff/landing**
- **Cruise power for long range flights**
- **< 15-minute fast recharge capability**
- **Improved safety for thermal runaway events**
  - Inherently safer chemistries & battery designs
- **Advanced packaging concepts – mechanical, thermal**
- **Structural integration – multifunctional concepts**
- **Concepts for all-electric and hybrid-electric**

BEAST (Battery Enclosures for Advanced Safety & Thermal) Project Motivation

Task Lead: Pat Loyselle (216)433-2180

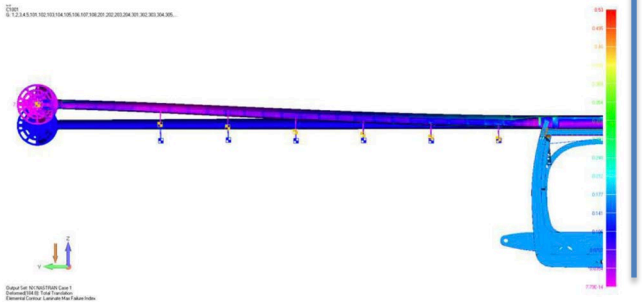
Goal

Improve performance & safety of EAP batteries through integration of pack layout, thermal management design and cell chemistry

- High energy density batteries are **primary** barrier for EAP

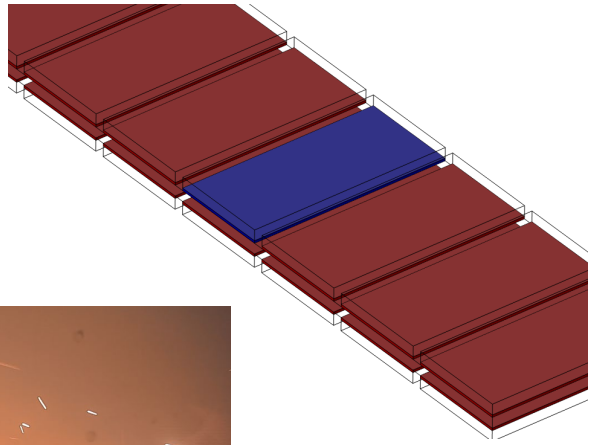
Challenges

- Batteries in flexible structures must handle a challenging load environment while maintaining performance & safety
- ***MASSIVE uncertainty around thermal management system performance, pack level integration, and pack life in aviation applications***



Approach

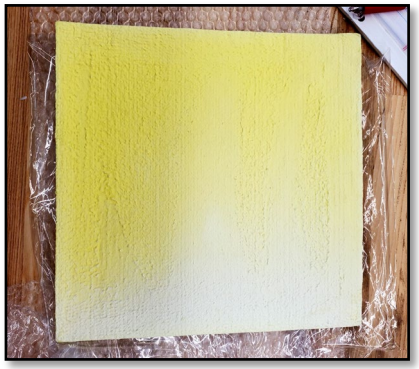
- Integration of oscillating heat pipes, phase change material & aerogel
- Cell-level thermal runaway to adjust thermal modeling results and inform safety risks
- Tests for modeling, durability & survivability – customized bending rig for wing stresses
  - Rapid feedback & redesign



Thermal Management Features

Aerogel

- Polyimide composite with Nomex fibers
- Very lightweight, density ~ 0.23 g/mL
- Great insulator, thermal conductivity ~ 28mW/m-K
- Nonflammable
- Durable – tensile modulus 130 MPa, Compressive Modulus 40 MPa



Aerogel

Phase Change Material (PCM)

- Organic crystalline wax with melting point at 47 C
- PCM incorporated into open cell ~95 % porous Cu foam to increase thermal conductivity
- PCM and Cu foam incorporated into Cu clad Mo tray with lid

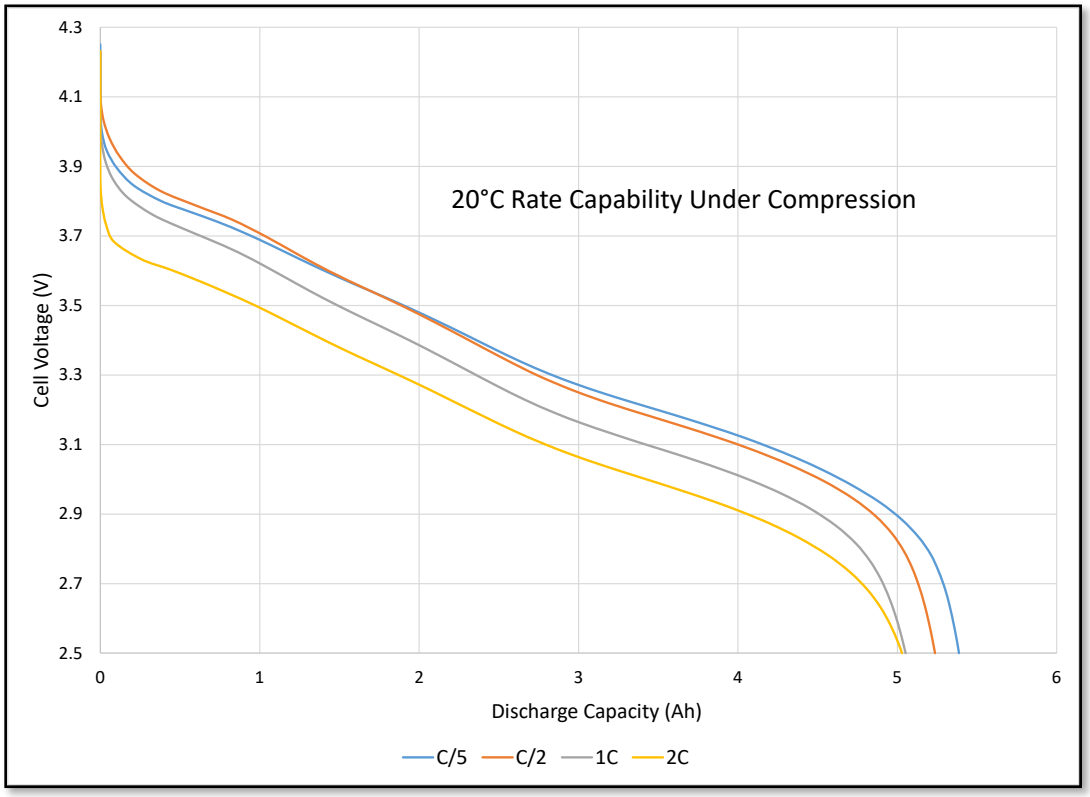
Heat Pipes

- COTS Hi-K plate from Advanced Cooling Technologies
- Al heat spreader with 4 internal heat pipes

PCM in Cu foam

Test Article

Amprius CL0063 "High Energy Density Power Cell"
- Chemistry: Silicon / NMC
- Nameplate Capacity: 5.2 Ah (C/5) / 5.0 Ah (2C)
- Specific Energy: 410 Wh/kg (C/5)



20 CL0063 cells received

NASA GRC data

Rate	C/5	C/2*	1C*	2C*
Wh/kg (2-cell avg)	406	393	372	360

*Cells compressed at higher rates

Thermal Runaway Tests

Test Setup

Cells at 100% SOC

3 fixture setups:

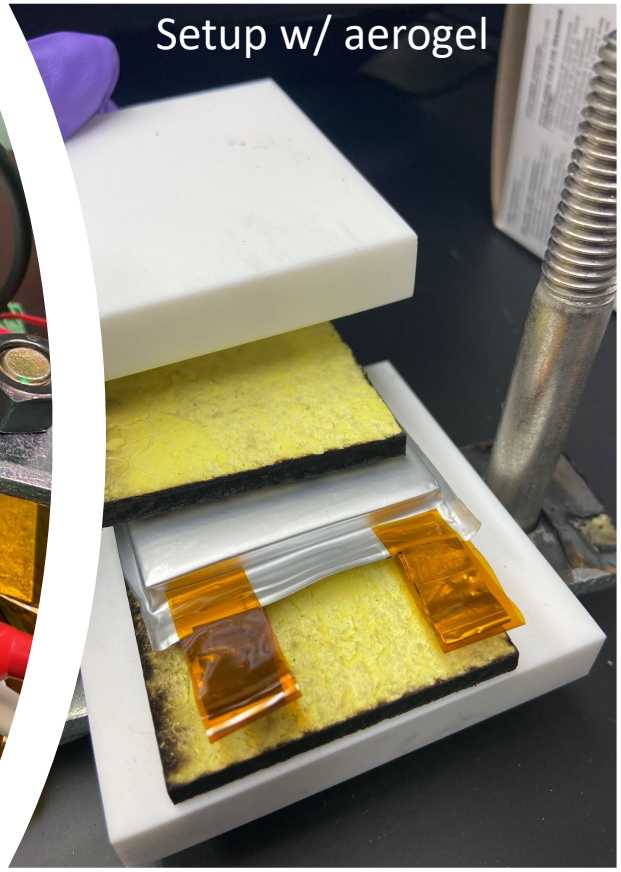
- Bare cell (no compression)
- Compression plate
- Compression plate w/ 2 aerogel layers

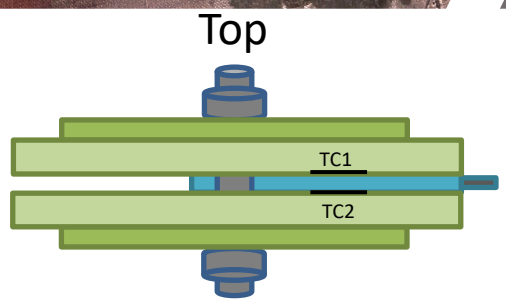
Surface thermocouples

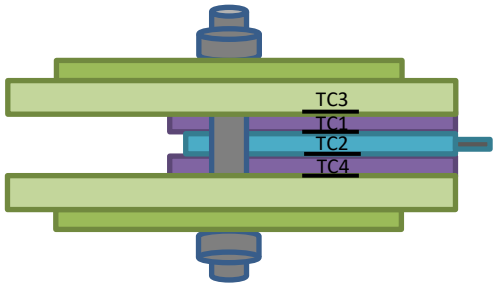
Cells secured in blast box (air)

1C overcharge until TR

LED lighting with single camera

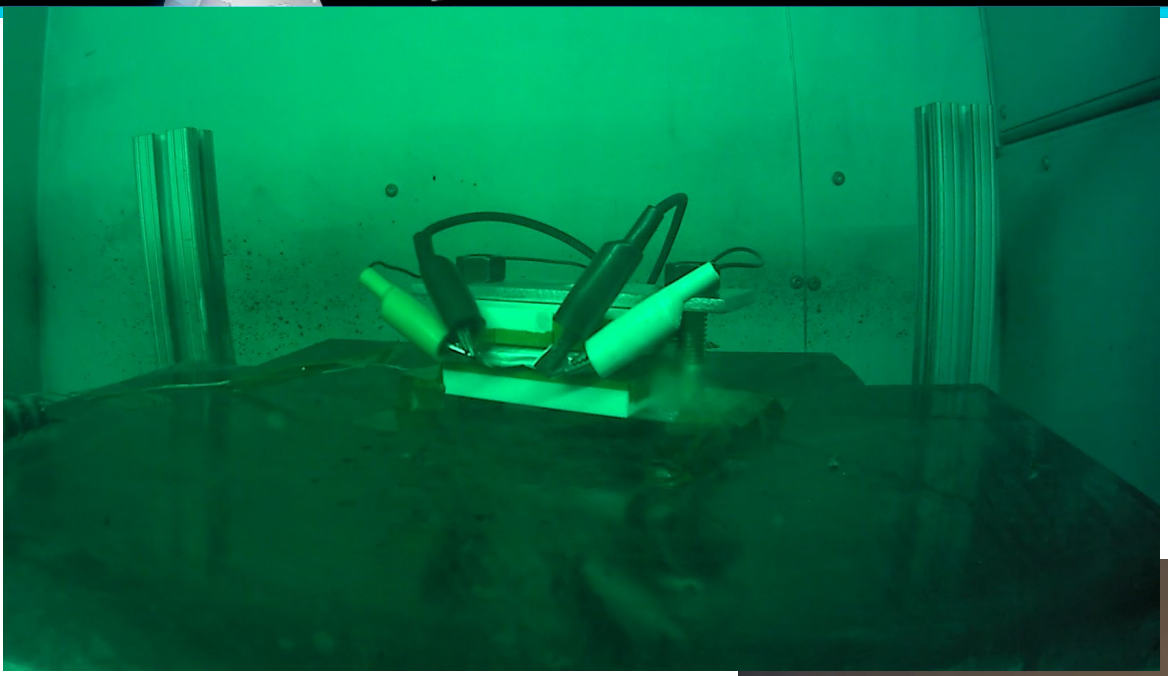






Thermal Runaway with Compression Fixtures

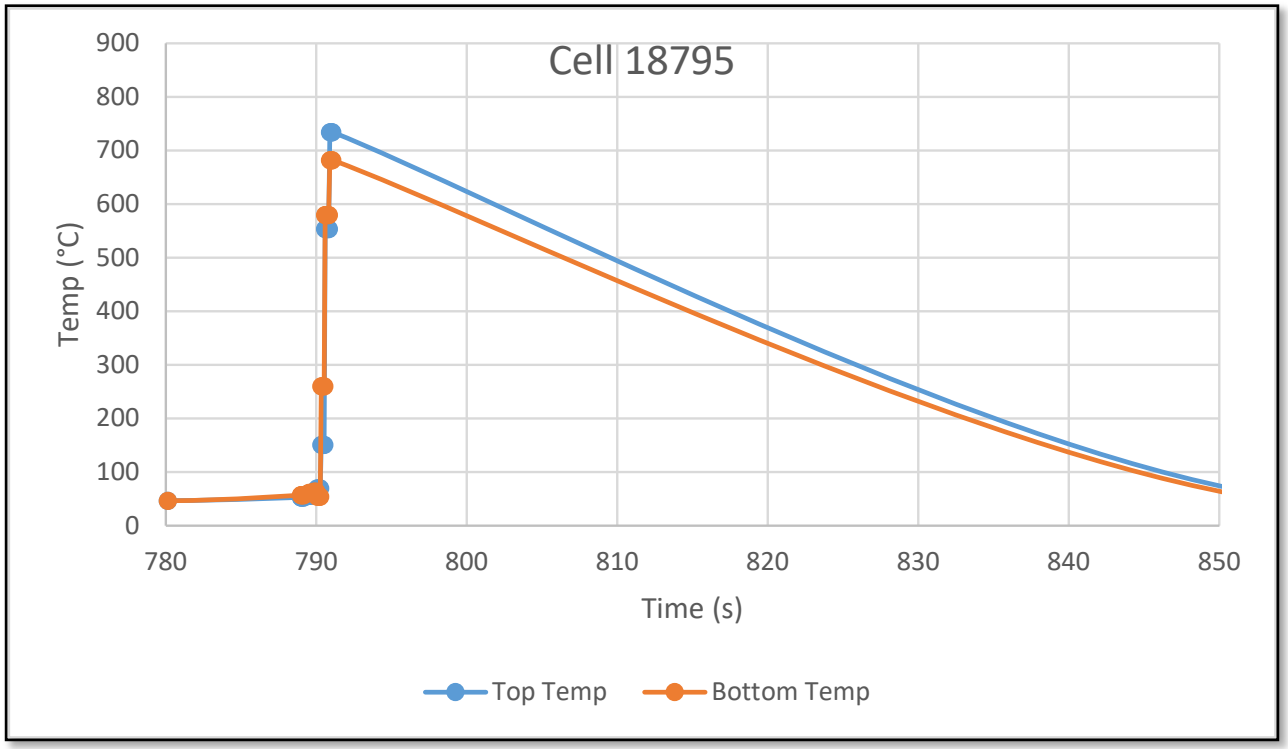
Video Clips – Compressed Cells



Standard Compression

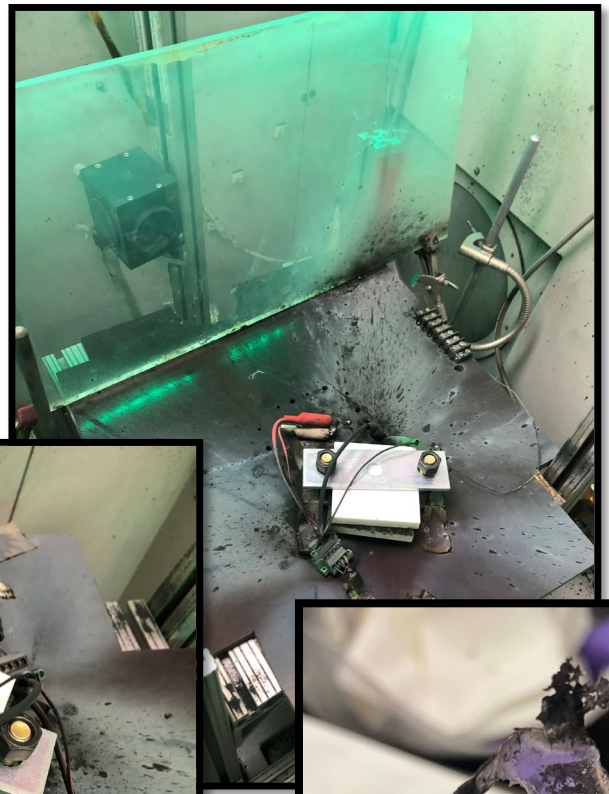
- TR in as little as 13 minutes at 1C
- Venting near tabs
- Max TC readings 734°C
- Inconsistencies in time to TR event, location of venting, path of ejecta

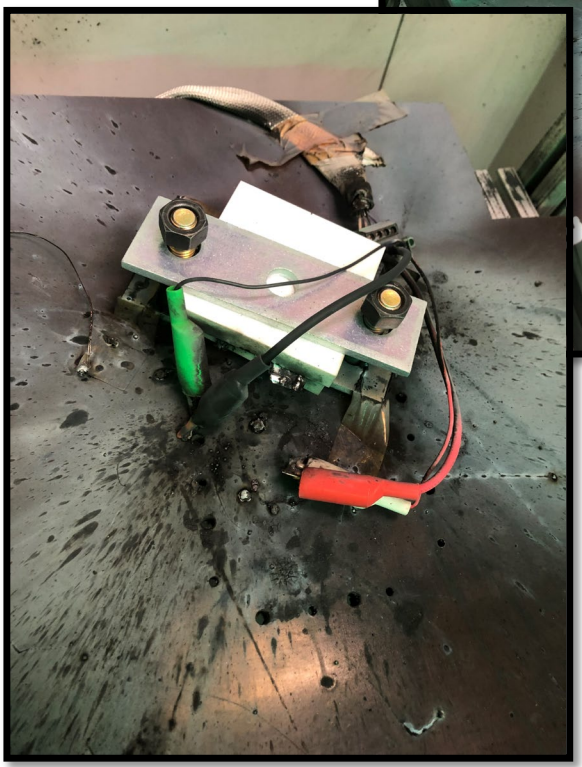
Compressed Data



- **Thermocouples on both flat cell surfaces to determine ΔT across cell**
- **Rapid self heating >5° C/s began ~789s with cell at 53° C**

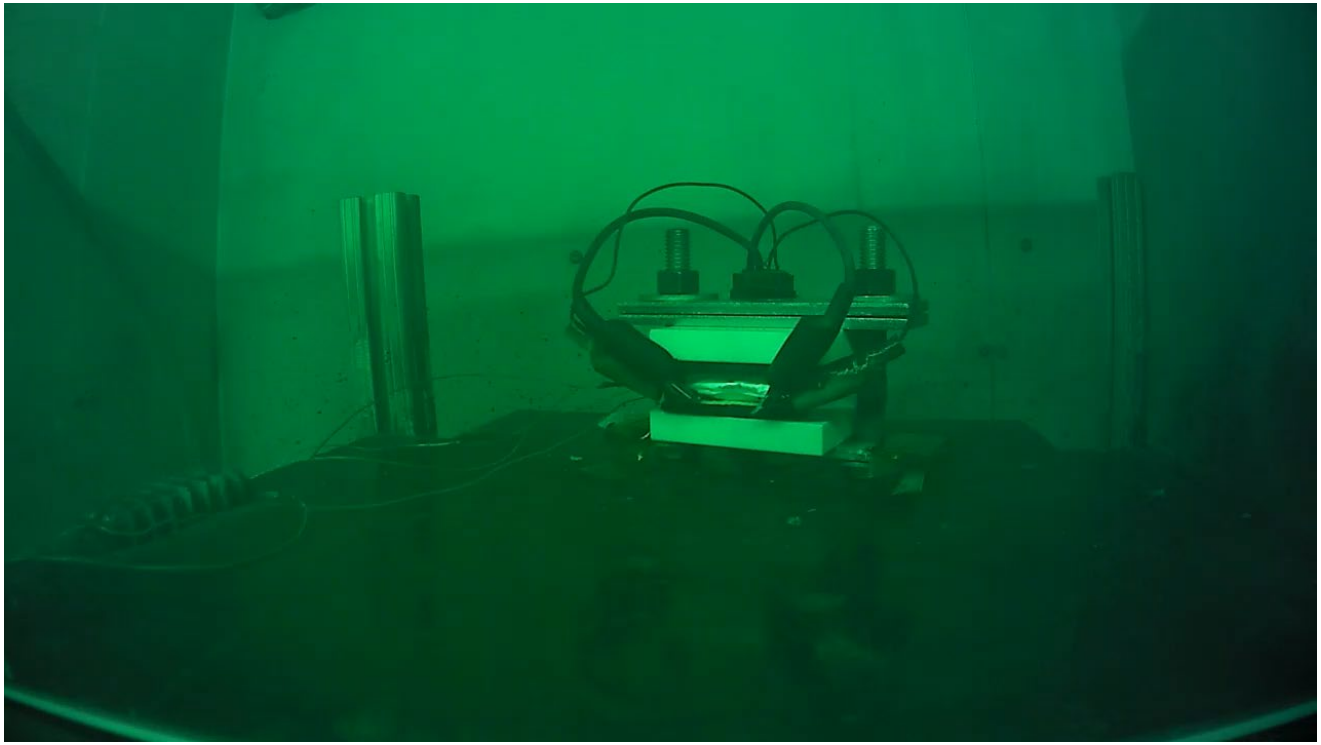
Post-test Photos of Compressed Cells





Thermal Runaway with Compression Fixtures and Aerogel Layers

Video Clips – Aerogel Cells



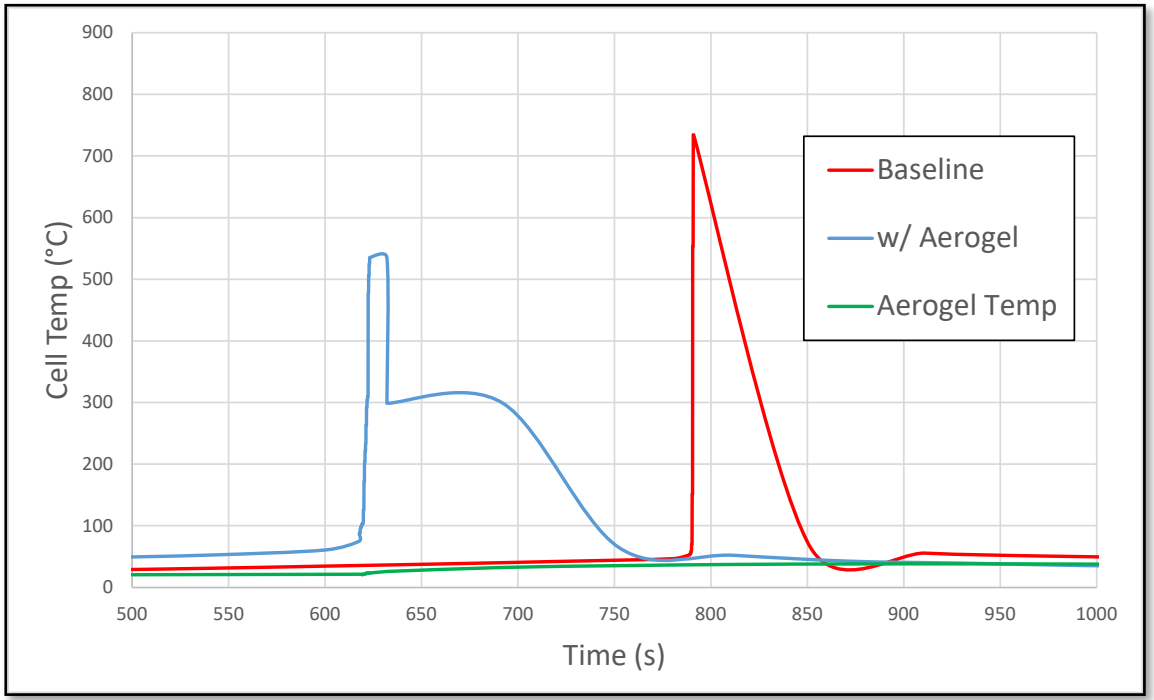
Aerogel Layers

- Faster TR – 10 min
- Venting near tabs
- Max TC readings ~535°C – lower than compressed cells without aerogel
- Aerogel chars but does not burn

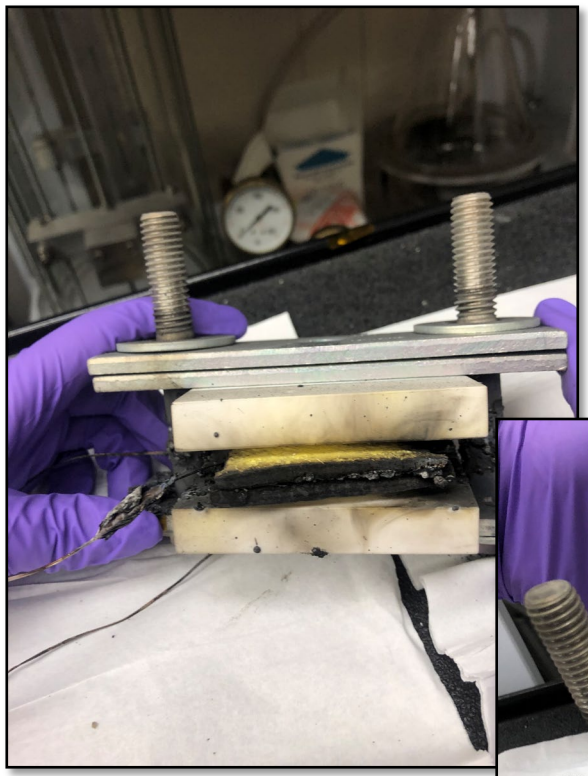
Effect of Aerogel

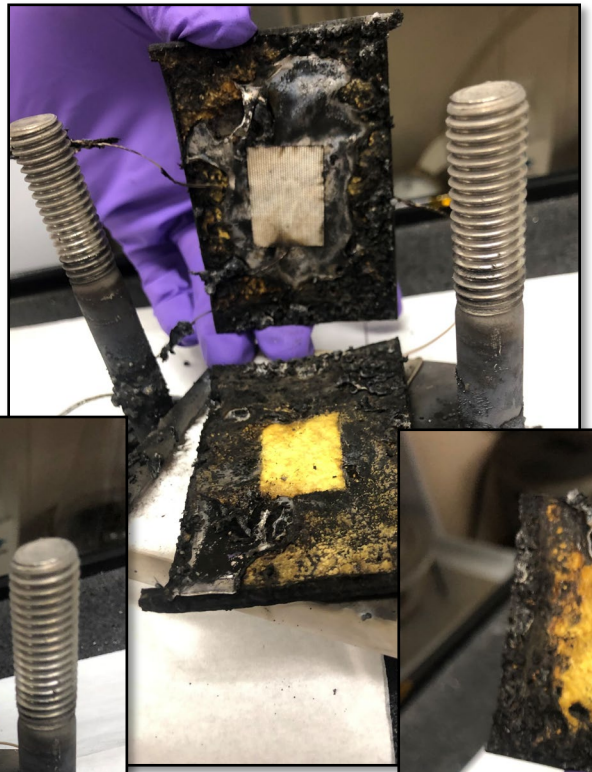
- **Faster/shorter TR event w/ aerogel**
  - 10 min vs 13 min to TR onset
  - Shorter burn time
- **Lower max temp w/ aerogel**
  - $Tmax_{aerogel} < 40^{\circ}$ C
- **Higher T_{onset} & faster thermal ramp w/ aerogel**

Cell	Feature	Time to TR (s)	Temp at TR Onset (°C)	Max Cell Surface Temp (°C)
18795	None	789	52	734
18797	Aerogel x2	617	86	535



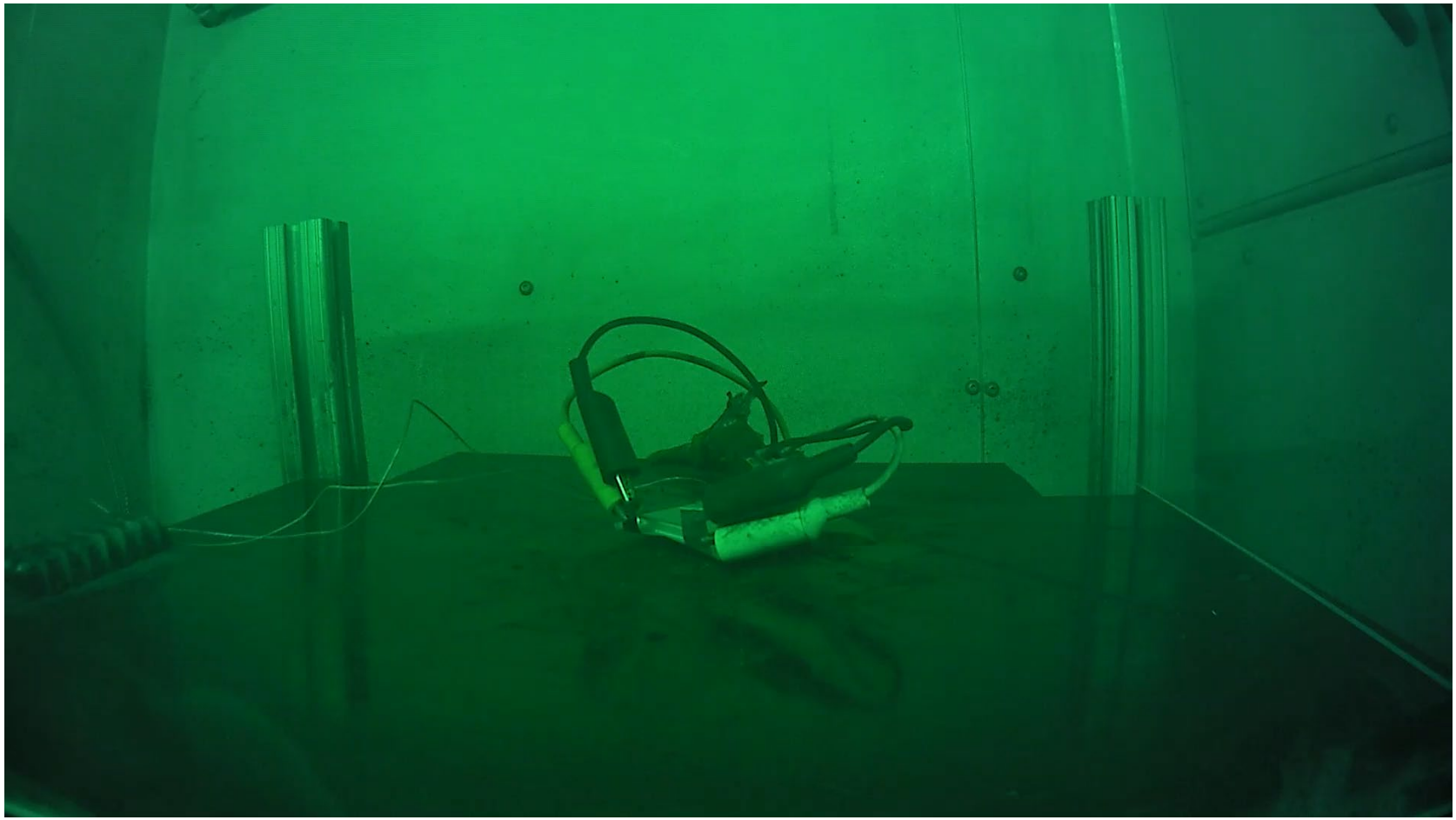
Post-test Photos of Aerogel Cells





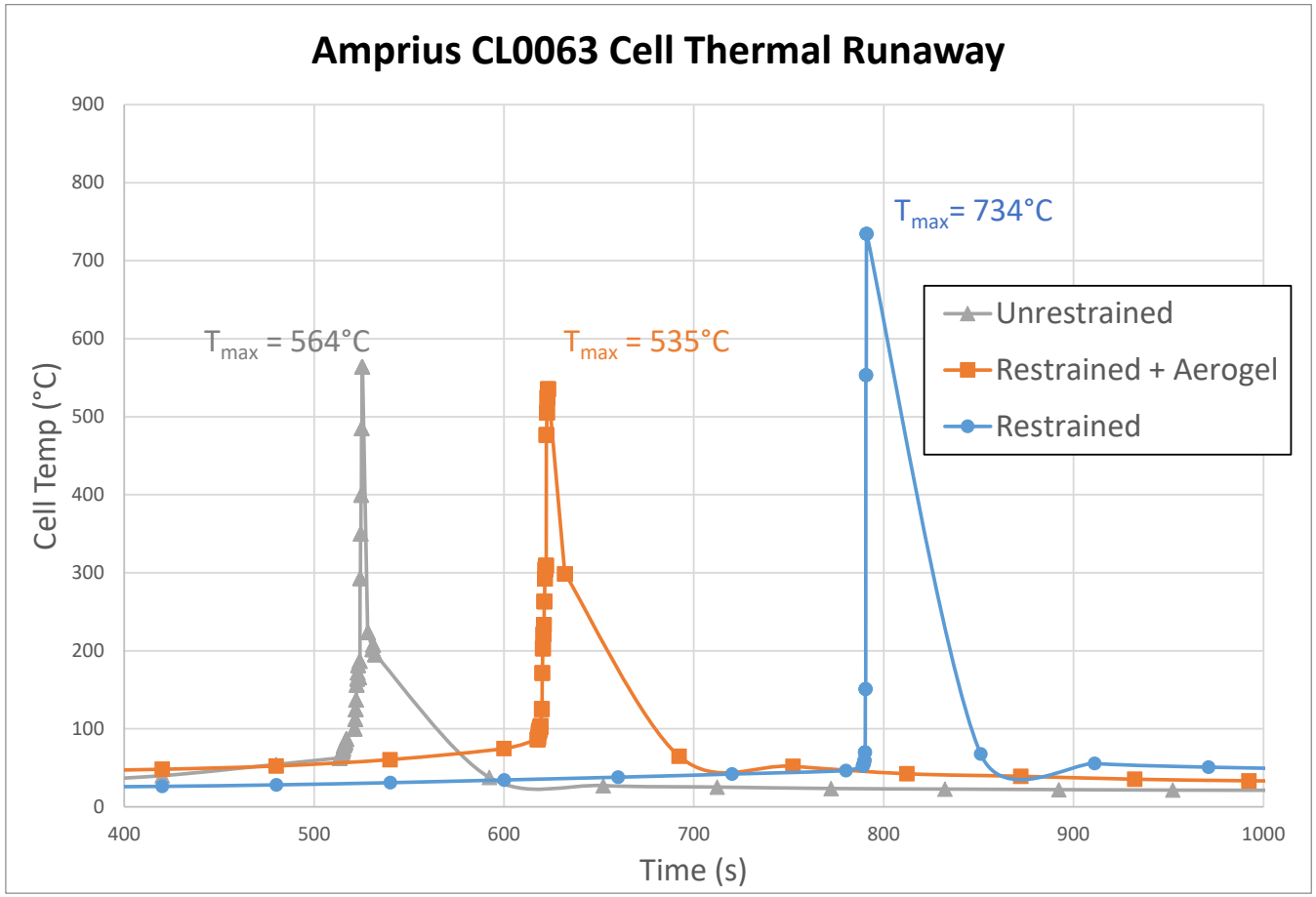
Thermal Runaway without Compression Fixtures – Bare Cells

Bare Cell w/out Compression



- Fastest event of all – TR at ~520s
- Significant swelling and venting
- Ejecta expelled across blast box as pouch material burst open

Key Takeaways



- Cells under compression entered TR >30% later than cells without restraint hardware
- Aerogel insulated cells well, increasing rate of temp climb, but lowering TR onset temp and time to TR

Next Steps

Pending Tests

- **8s1p pack with aerogel, PCM, OHP**
  - Electrochemical performance baseline
  - Bending rig tests to simulate wing forces
  - Thermal profile across multi-cell design with integrated thermal features

Future Plans

- Reduce metal hardware
- Integrate composites & carbon fiber concepts
- Additive manufacturing
- Integrate sensor/NDE and solid-state pouch technologies

THANK YOU FOR YOUR ATTENTION

Questions/Comments -

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